Medical System Foundation Overview for Long-Duration Lunar Orbit and Lunar Surface Operations (LDLOLS) Missions

Human Research Program
Exploration Medical Capability Element

HRP IWS
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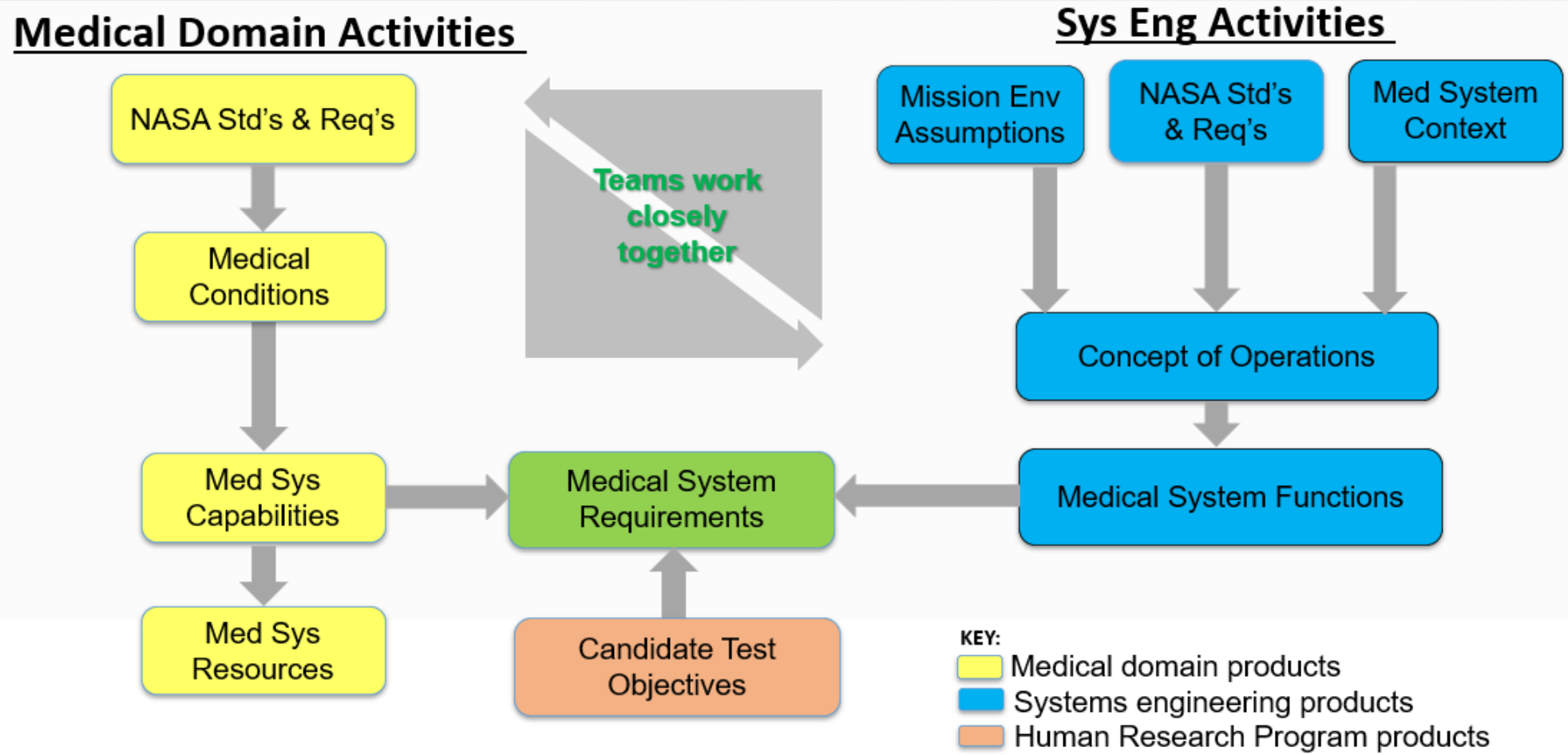
"Expanding the Boundaries of Space Medicine and Technology"

Motivation Behind this Effort

- How will the provision of medical care change for deep-space, long-duration exploration missions?
- How can ExMC help to facilitate communication among exploration program managers, engineers, and clinicians?
- Identified need to:
  - Assist in the development of evidence-based medical system **requirements** and their rationales
  - Enable **traces** among requirements, medical capabilities, medical conditions, and medical resources.
  - Advance and refine the medical **system architecture** for future mission planning.
  - Present information in an easily accessible format that is **understandable** across disciplines.

What is the LDLOLS Medical System Foundation?

- A process of integrating clinical and systems engineering inputs to generate recommendations for medical system design



ExMC's Approach

- We followed the **same robust process** that ExMC created for the Short Duration Lunar Orbital Foundation presented in 2020.

- All LDLOLS model content was developed by a **multidisciplinary team** (e.g., clinicians, scientists, and engineers) across several NASA centers (JSC, ARC, GRC, LaRC)

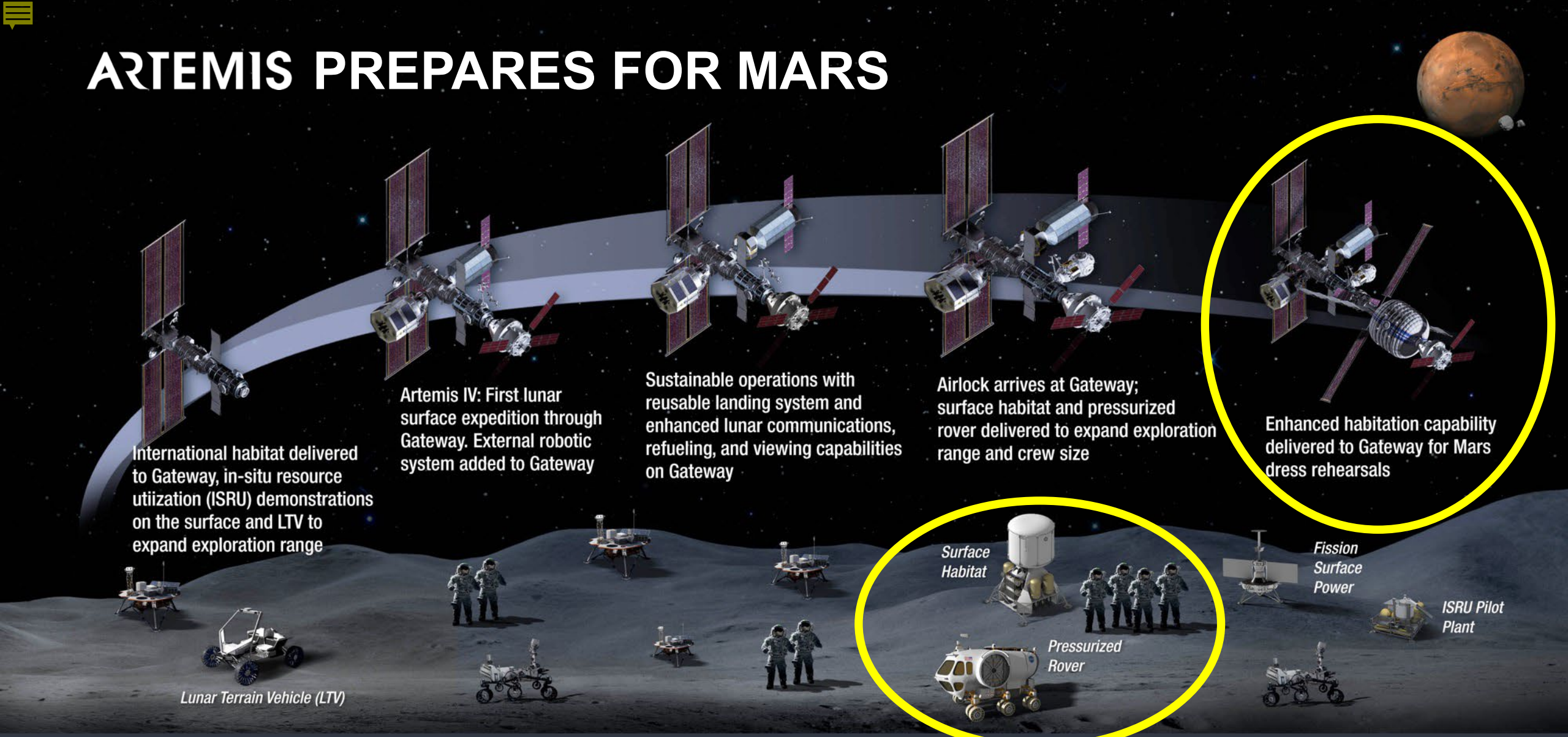
- Employ systems engineering principles (similar to other vehicle systems) and use a **model-based systems engineering (MBSE)** approach to capture information
  - MBSE recognized by the Office of the Chief Engineer as **best practice** for system design and is consistent with the use of digital architectures by Exploration Programs
  - MBSE makes it easy to determine how changes to high level assumptions or requirements lead to changes in the medical system architecture
  - Enable users to visualize the medical system functions, conditions, capabilities, and resources and understand how they all trace to medical system recommended requirements.
    - Assess the impact of removing resources via traces to functions/capabilities/conditions.
    - Identify medical requirements that may need to be levied on other vehicle systems.

LDLOLS Foundation Outputs

- Principle Components of the Foundation
  1. A **Concept of Operations** baselined to deep space, long-duration exploration missions
  2. A corresponding **medical condition list, clinical capabilities set, and medical resource set**
  3. Recommended **medical system requirements**
  4. Model to capture and visualize the Concept of Operations (ConOps), medical artifacts (e.g., medical condition list, clinical capabilities, medical resources), and medical system requirements.

- Intended to be a starting point (a “Foundation”) for early medical system design to build from and that can be tailored for specific missions

ARTEMIS PREPARES FOR MARS



SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | U.S. GOVERNMENT, INDUSTRY, AND INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

Assumptions Used for the LDLOLS Foundation

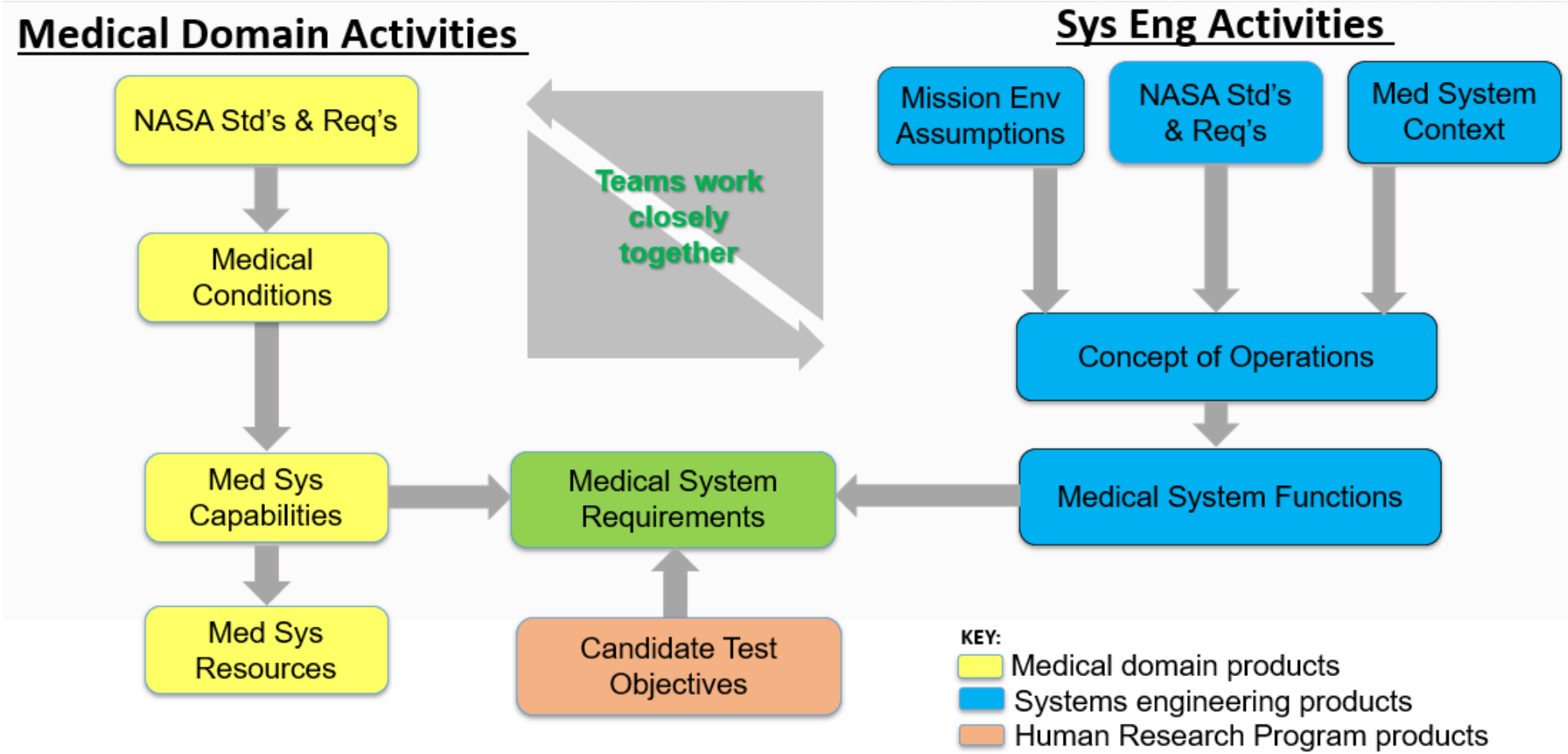
Parameter	Assumption
Crew composition	Four-person crew (at least 2 crew medical officers)
Mission duration	Total: ~ 9 months Lunar Orbit: 6 months Lunar Surface: 3 months
Location	Lunar orbit and Lunar South Pole
Target Level of Care	Level of Care IV, NASA-STD-3001 Volume 1, Revision A* *will be updated to current 3001 revision in FY23
EVAs	Lunar orbit (contingency only) Lunar surface (frequent, nominal EVAs on foot, with pressurized rover, with unpressurized rover)

The Development and Review Process

- LDLOLS Foundation content was **developed and reviewed iteratively** by the ExMC **Systems Engineering (SE) team** and **Clinical and Science Team (CST):**
  - SE team is comprised of **systems engineers** from a variety of engineering and science backgrounds (e.g., systems, bio/biomedical, aerospace, mechanical, and human factors engineering).
  - CST is comprised of **ExMC and SD clinicians** such as pharmacists, nurses, and physicians (e.g., aerospace, emergency, internal, physical med & rehab, physician-astronaut) and provides clinical expertise and a spaceflight medicine knowledge base.

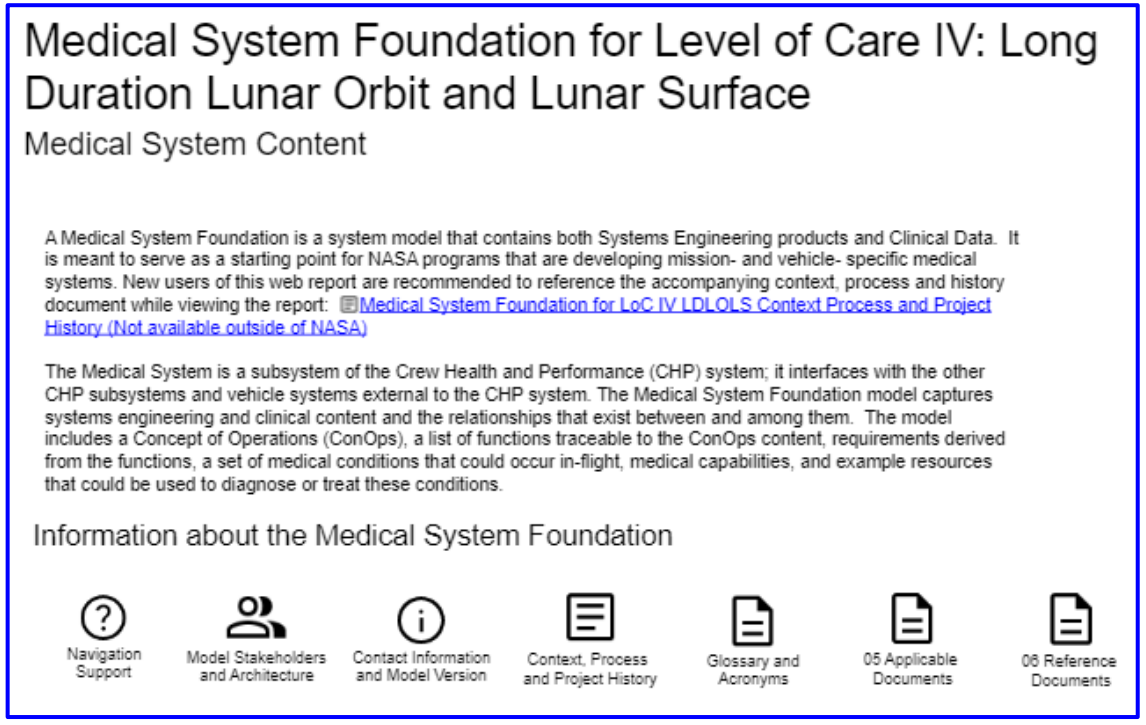
- The ExMC SE and CST teams followed all available **NASA processes and best practices** for Foundation development:
  - NPR 7123.1C – NASA Systems Engineering Processes and Requirements
  - JPR 7210.3C – Program/Project Management and Systems Engineering
  - SP 6105 rev2 – NASA Systems Engineering Handbook
  - Expanded Guidance for NASA Systems Engineering – Volume 1 and 2

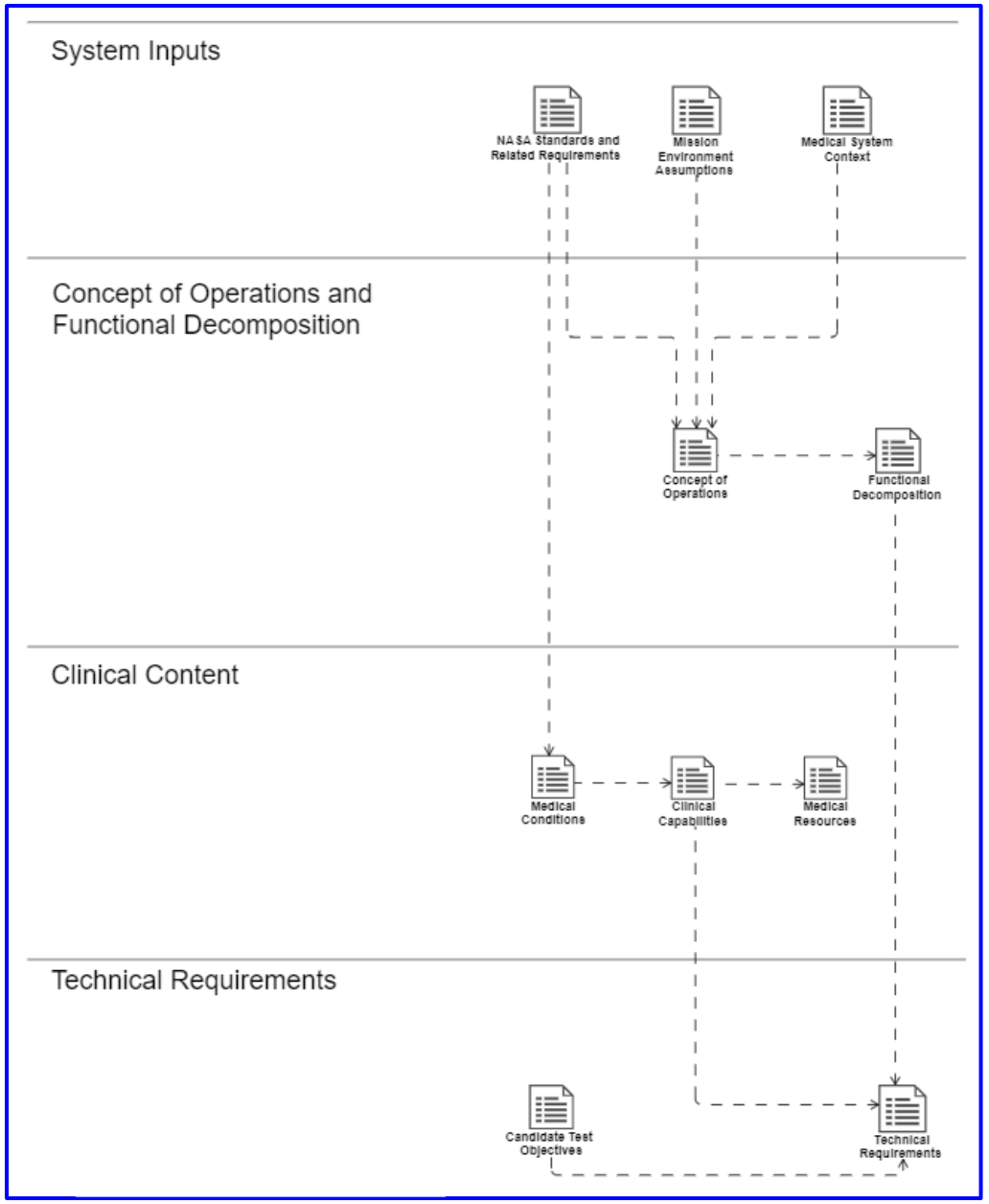
LDLOLS Model Follows Foundation Processes and Inputs



Medical System Contents – High Level Organization

- System inputs
- Concept of Operations (ConOps) and Functional Decomposition
- Clinical content
- Technical requirements (functional, non-functional, and interface)





NASA Standards and Requirements

This page includes the following:

- NASA 3001 Standards (Vol 1 and 2)
- ISS MORD (Medical Operations & Requirements Document)
- Representative program/vehicle high-level (Level 2 and 3, respectively) requirement tables
- Traces between NASA standards, ISS MORD, and related requirements

Level 3 Habitat Requirements with Traces

#	Name	Text	Rationale	NASA STD Derived	Historical Trace	Derived From
1	L3-Hab-0001 Provide Clinical Care	The Habitat shall provide clinical care.	Clinical care provides in-mission capabilities for the prevention, diagnosis, treatment, monitoring, and long-term management of medical conditions.	Vol1-RevA - 4.4.3.2 Level of Medical Care Vol1-RevA - 4.1.5 Level of Care Four Vol2-RevB - 7.5.1 Medical Capability	RevE - 5.2 In-Flight Medical Evaluations	L2-Prog-0001 Crew Medical Care Management
2	L3-Hab-0002 Provide Medical Imaging	The Habitat shall provide medical imaging.	Imaging provides in-mission capabilities for diagnostic imaging in support of the provision of clinical care and includes all hardware, software, and analysis capabilities required for the capturing and processing of diagnostic imaging.		RevE - 6.3.6 In-Flight Biomedical Monitoring and Diagnostics	L2-Prog-0001 Crew Medical Care Management

Example trace table of L3 requirements with related 3001 standards and ISS MORD and L2 requirements

Mission Environment Assumptions

The Medical System operates within the following environments. Attributes of each environment (e.g., duration in each environment) were collected before defining the ConOps.

In Scope

Lunar Orbital Vehicle

Lunar Orbital EVA Suit

Lunar Surface Habitation Module

In Scope

Lunar Surface EVA Suit

Pressurized Rover

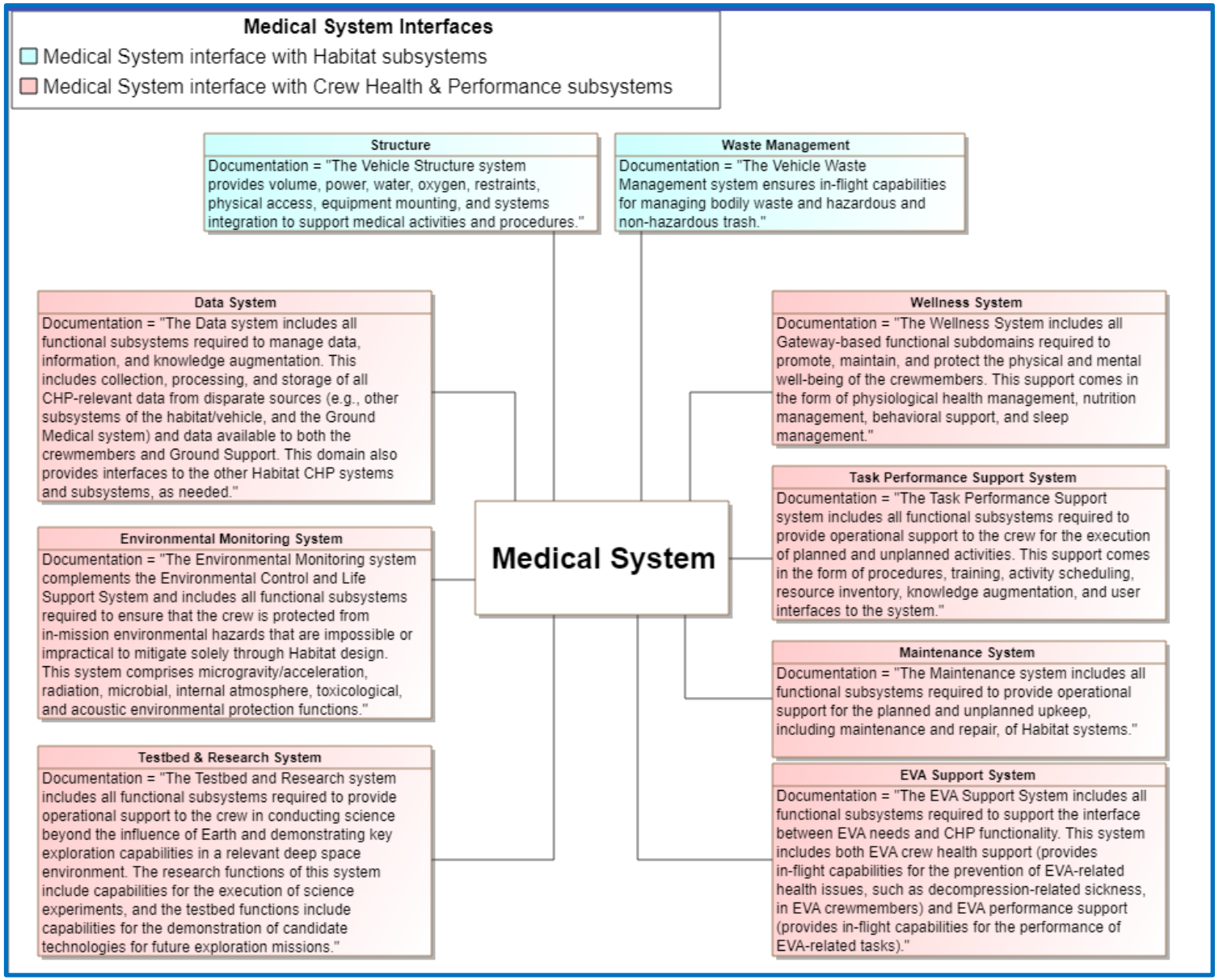
Unpressurized Rover

Out of Scope

Lunar Transit Vehicle

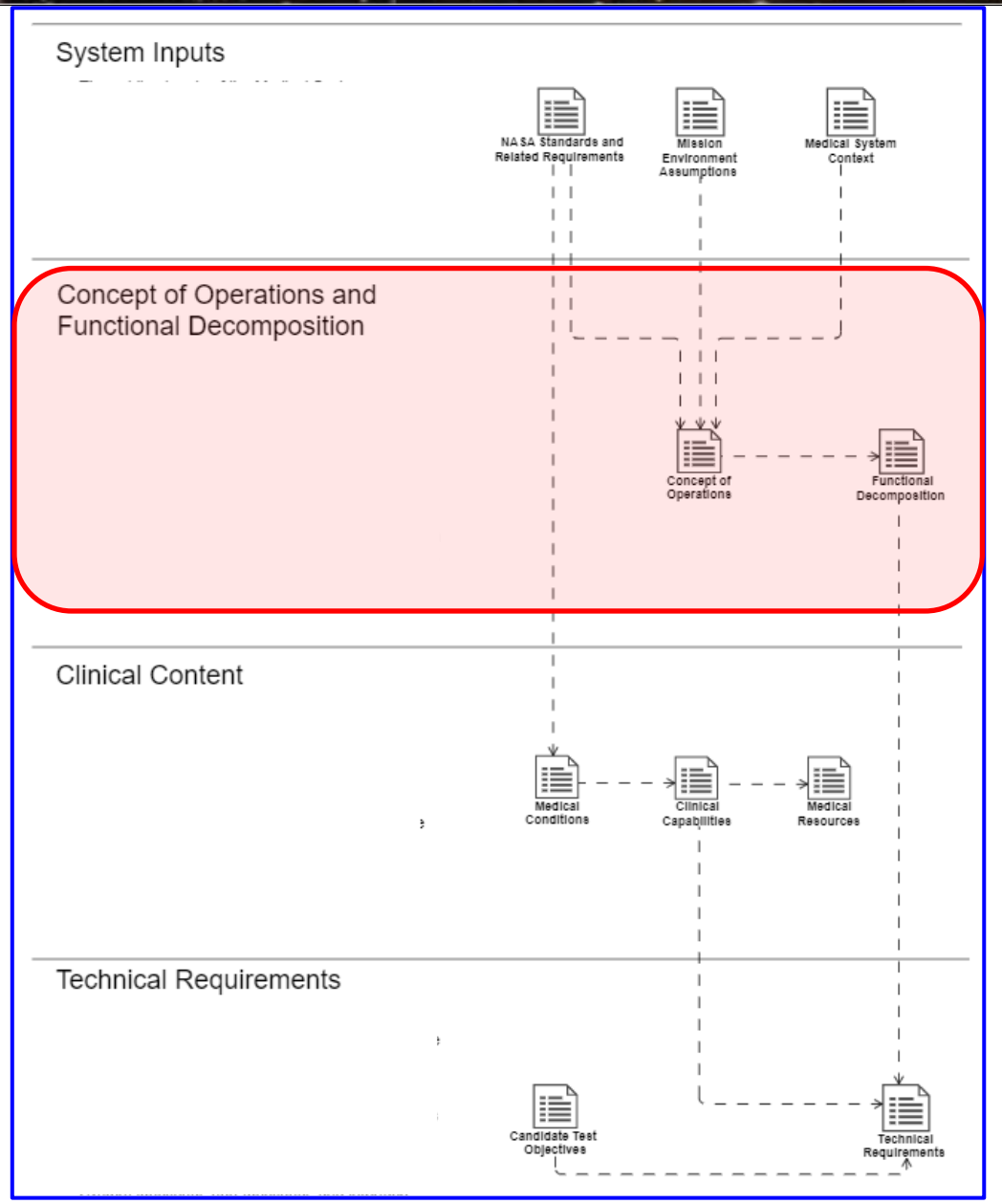
Lunar Ascent/Descent Vehicle

Medical System Context



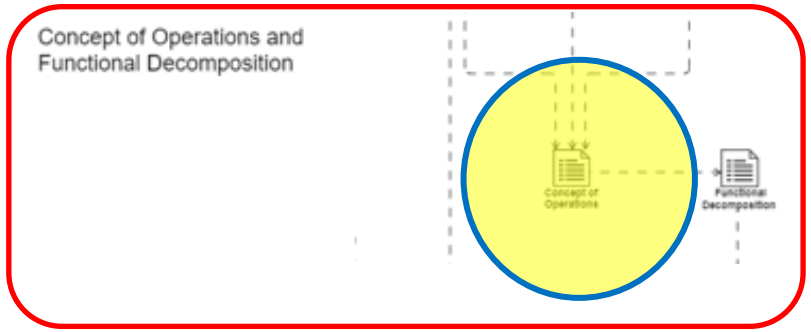
This diagram shows the context of the Medical System within the greater Crew Health and Performance (CHP) system and Habitat subsystems.

Concept of Operations & Functional Decomposition



Concept of Operations (ConOps)

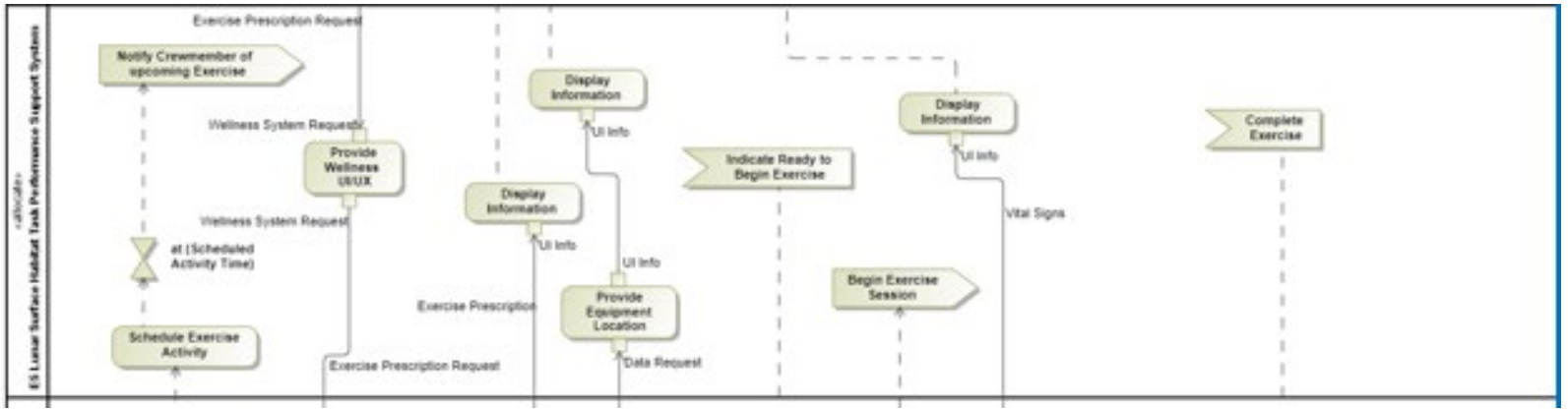
- **S**takeholder needs & system goals
- Purpose and scope
- Mission descriptions & assumptions
- Environments
- Scenario narratives
- Scenario activity diagrams



Scenario Narrative

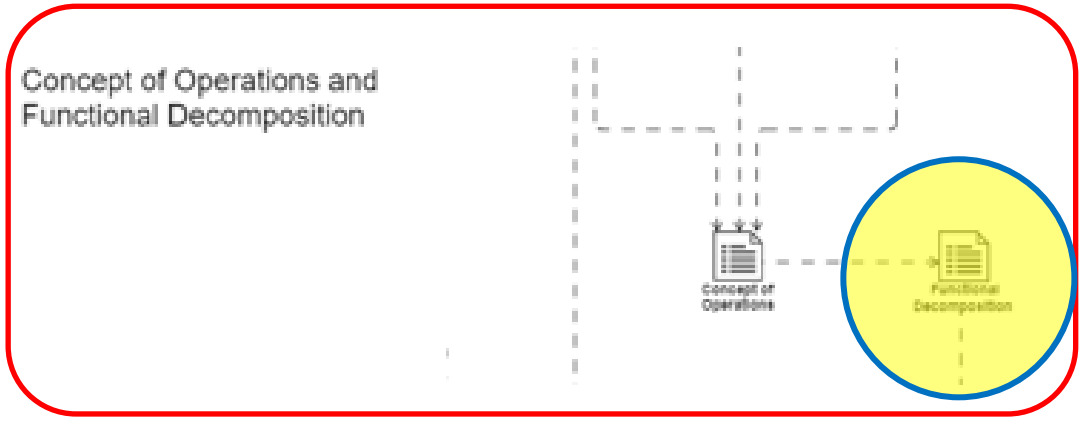
The Habitat Medical System generates a workout prescription and schedules an upcoming session. The habitat crew scheduling system sends an alert to a crewmember's personal electronic device that she has an upcoming scheduled exercise session. She prepares for her workout and translates to the exercise system. The crewmember activates the user interface of the exercise system, and the device verifies her identity and logs her in. The interface displays her personal exercise prescription, which had previously been uplinked to the Habitat Medical System. After referencing and following written instructions for preparing to use the equipment, she notifies the exercise system that she is ready to begin her exercise. Her vital signs are transmitted via a wireless interface. Heart rate data are displayed to the crewmember as she exercises. Upon completion of her exercise session, the exercise system transmits the vital signs, exertion, and force data to the Medical System, which downlinks the data to the Ground Medical System at the next communication opportunity. The crewmember disconnects the loading mechanism and stows the harness. She then heads back to the hygiene station to get cleaned up and continue with the rest of her workday. She makes a mental note to review her exercise session data from her personal computing device during her rest period.

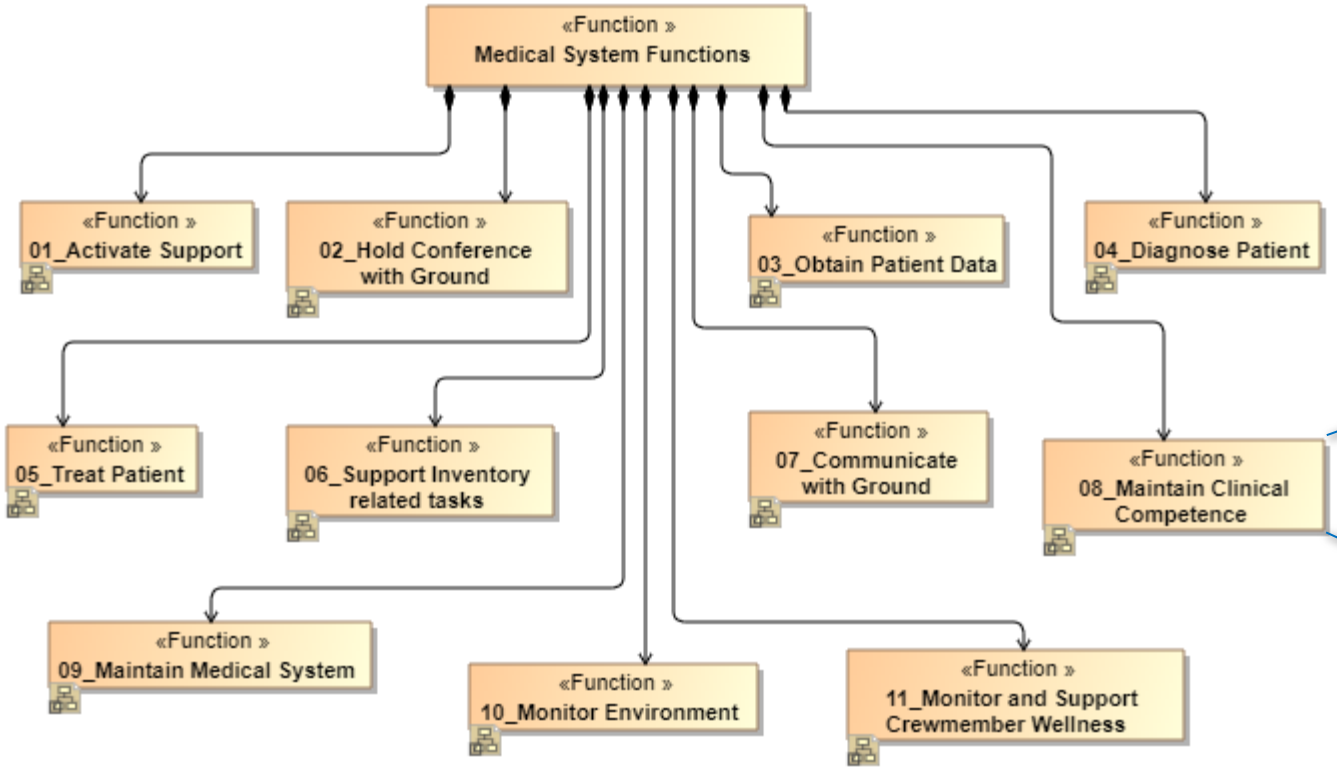
Excerpt of the activity diagram of the Conduct Exercise scenario narrative



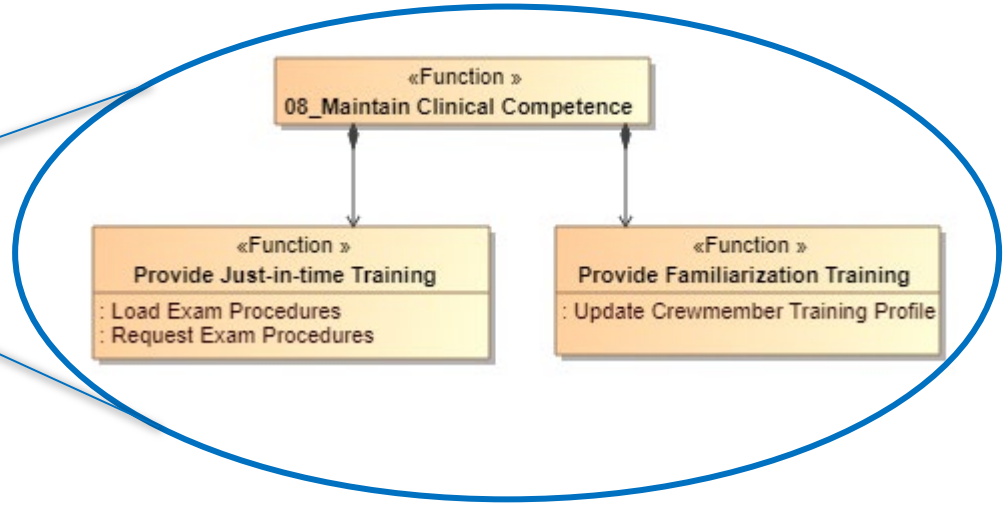
Medical System Functions

These function blocks represent key system features and were used to derive representative medical scenarios.





Subfunctions and mapped activities from the scenario activity diagrams

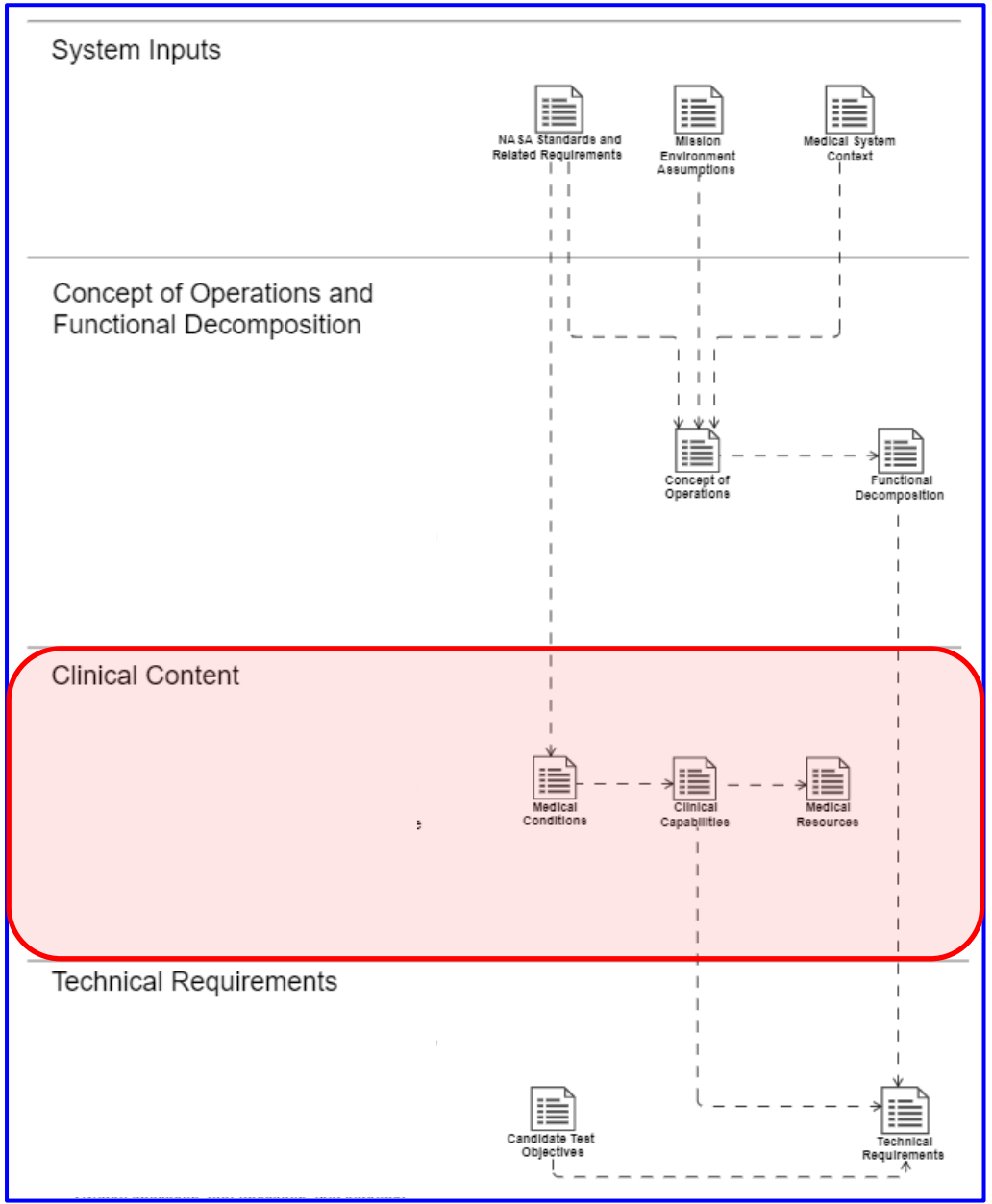


Clinical Content

Conditions – unplanned medical activities that occur during a mission and require medical evaluation, diagnosis, monitoring, treatment, or long-term management that has to be implemented by the crew

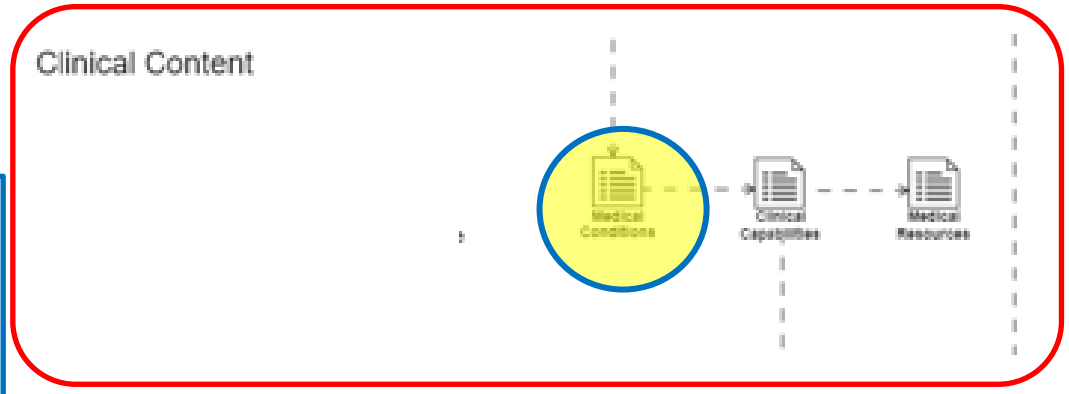
Capabilities – The skills and actions required to both diagnose and treat the related medical conditions

Resources – Consumables, devices, and pharmaceuticals needed to prevent, diagnose, treat, and provide long-term management of conditions



Medical Conditions

The Conditions page includes the table of IMPACT medical conditions and the sources used to derive this list



IMPACT Medical Conditions List

Medical conditions (e.g., illnesses or injuries) are unplanned medical activities that occur during a mission and requ
diagnosis, monitoring, treatment, or long-term management (such as rehabilitation and recovery) that has to be imp

Medical Conditions List

The conditions list was derived from the following sources:

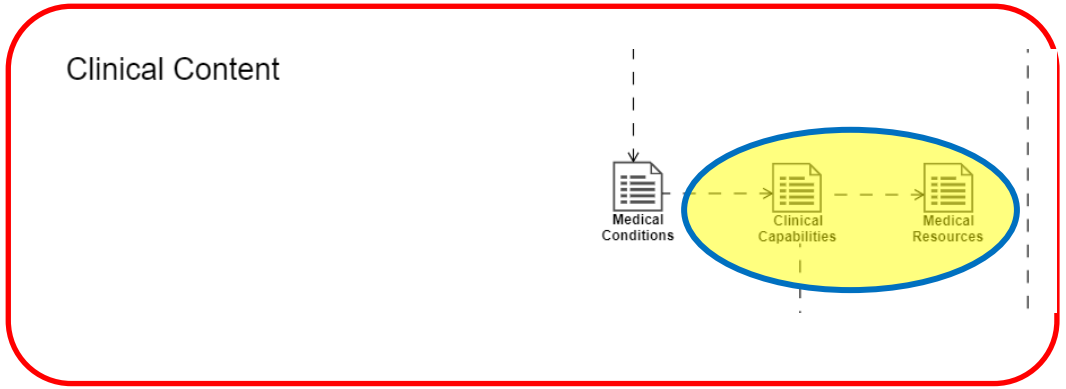
- Lunar Extravehicular Activity (EVA) Incapacitation Condition List (No Link available)
- Artemis Phase I: Functional Medical Concept of Operations Condition List (No Link available)
- The EL Team Condition List (Not available outside of NASA)
- Evidence Library Pilot Project Rochester Epidemiology (REP) Study Condition List (Unpublished)
- Evidence Library Pilot Project Spaceflight Condition List (Not available outside of NASA)
- Evidence Library Pilot Project Toxic Exposures and Injuries Condition List (Not available outside of NASA)
- IMCL Historical Spaceflight Condition List (Unpublished)
- IMM-GEN 309, Rev 1: IMM Medical Conditions List (IMCL) (IMM Portal Access Required)
- JSC-65722: Exploration Medical Condition List (EMCL) (Not available outside of NASA)

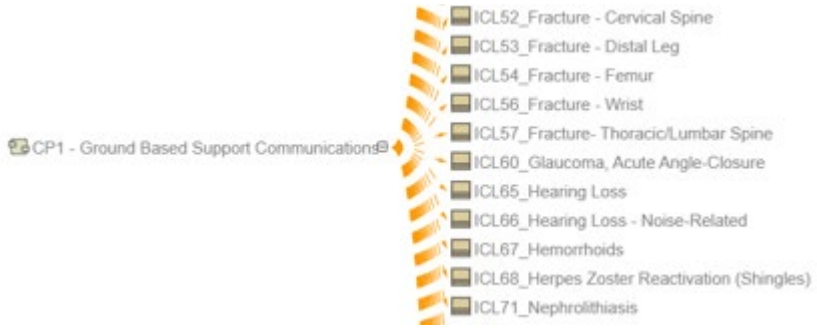
1	ICL1_Abdominal Wall Hernia
2	ICL2_Abnormal Uterine Bleeding
3	ICL3_Acute Coronary Syndrome
4	ICL4_Acute Radiation Syndrome
5	ICL5_Allergic Reaction (Mild To Moderate)
6	ICL6_Altitude Sickness
7	ICL7_Anaphylaxis
8	ICL8_Appendicitis
9	ICL9_Arthritis, Acute
10	ICL10_Atrial Fibrillation/Atrial Flutter
11	ICL11_Barotrauma (Ear/Sinus Block)

Clinical Capabilities and Resources

This page includes the following:

- Clinical capability tables
- Medical resources list
- Conditions ←→ Capabilities ←→ Resources
- Example graphical representations of mappings



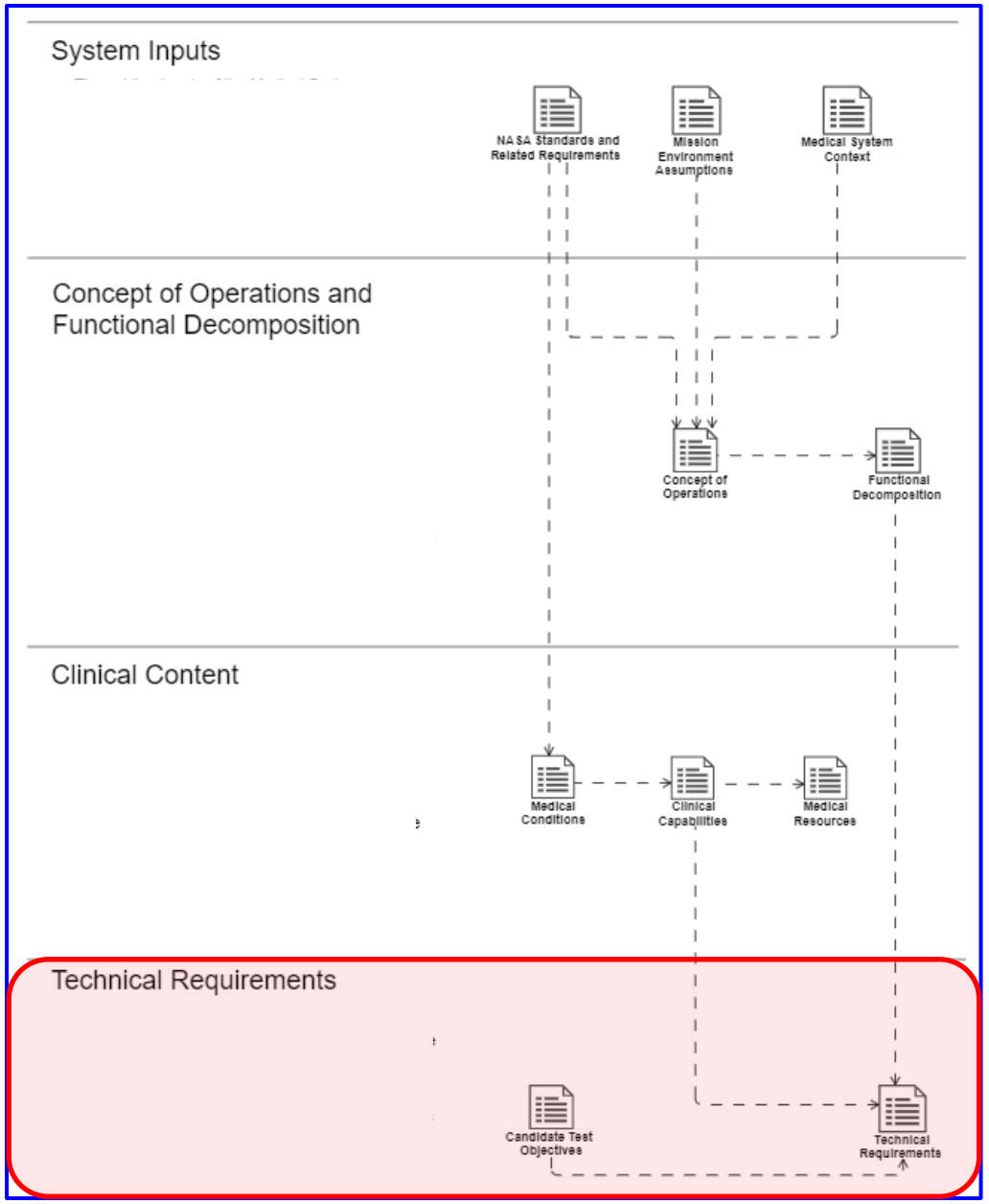


Example graphical representation of capability→ condition mapping

Template Master Equipment List

#	Medical Resources	volume per unit	mass per unit	average power consumption per unit
1	Airway - Bag Valve Mask	6218.8908 cc	0.5806 kg	0.0 W
2	Airway - Device - Capnography Nasal Cannula	509.703239 cc	0.091172 kg	0.0 W
3	Airway - Device - Capnography Sensor	0.0 cc	0.0 kg	0.0 W
4	Airway - Device - Invasive Airway Tube Capnography Adaptor	199.3506 cc	0.031751 kg	0.0 W

Technical Requirements



HSRB Candidate Test Objectives (CTOs)

- Developed, baselined, and managed by the Human System Risk Board
- Constitute a set of research and testbed objectives for what NASA needs to operationally test in the deep space environment to enable Mars missions with acceptable risk
- They were used to inform the Research and Testbed Interface Requirements of the Foundation

Ex. CTOs

16	HS-16	R Validate the efficiency and effectiveness of methods and processes for flight crew to maintain and repair systems in support of progressively Earth-independent operations	(HS-16) Validate the crew effectiveness of maintainability and reparability methods and processes. Deep space and long duration missions will necessitate a much greater level of system-wide maintainability and reparability due to the long periods of time from launch to end of mission during which the vehicle and habitat systems will be operational. Crew will need to have supplies and skills to execute routine and critical repair and maintenance issues. The effectiveness of such methods and skillsets need to be evaluated and proven on the ground and on ISS before being relied upon for long duration missions. These validations need to consider systems engineering, mission/process/task design, habitability concerns, usability, workload, training, and more. Associated Human System Risks: • Risk of Reduced Crew Performance and of Injury Due to Inadequate Human-System Interaction Design Associated HRP Path to Risk Reduction: See HRP Path to Risk Reduction Link https://humanresearchroadmap.nasa.gov/intro/
17	HS-17	R Validate the efficiency and effectiveness of multimodal crew/system interactions, communication, and alerting	(HS-17) Validate a prototype multimodal communication/alerting system inflight. Select non-flight-critical alerts and messages to convey with the multimodal system. Compare salience of the signaling method with traditional methods, collecting time to respond to signal, errors in response, and subjective comments. Use the activity to test current designs and identify needed capabilities/requirements for future communication/alerting systems. Associated Human System Risks: • Risk of Reduced Crew Performance and of Injury Due to Inadequate Human-System Interaction Design

Requirements Development

Medical System Functions

Derived from ConOps

+

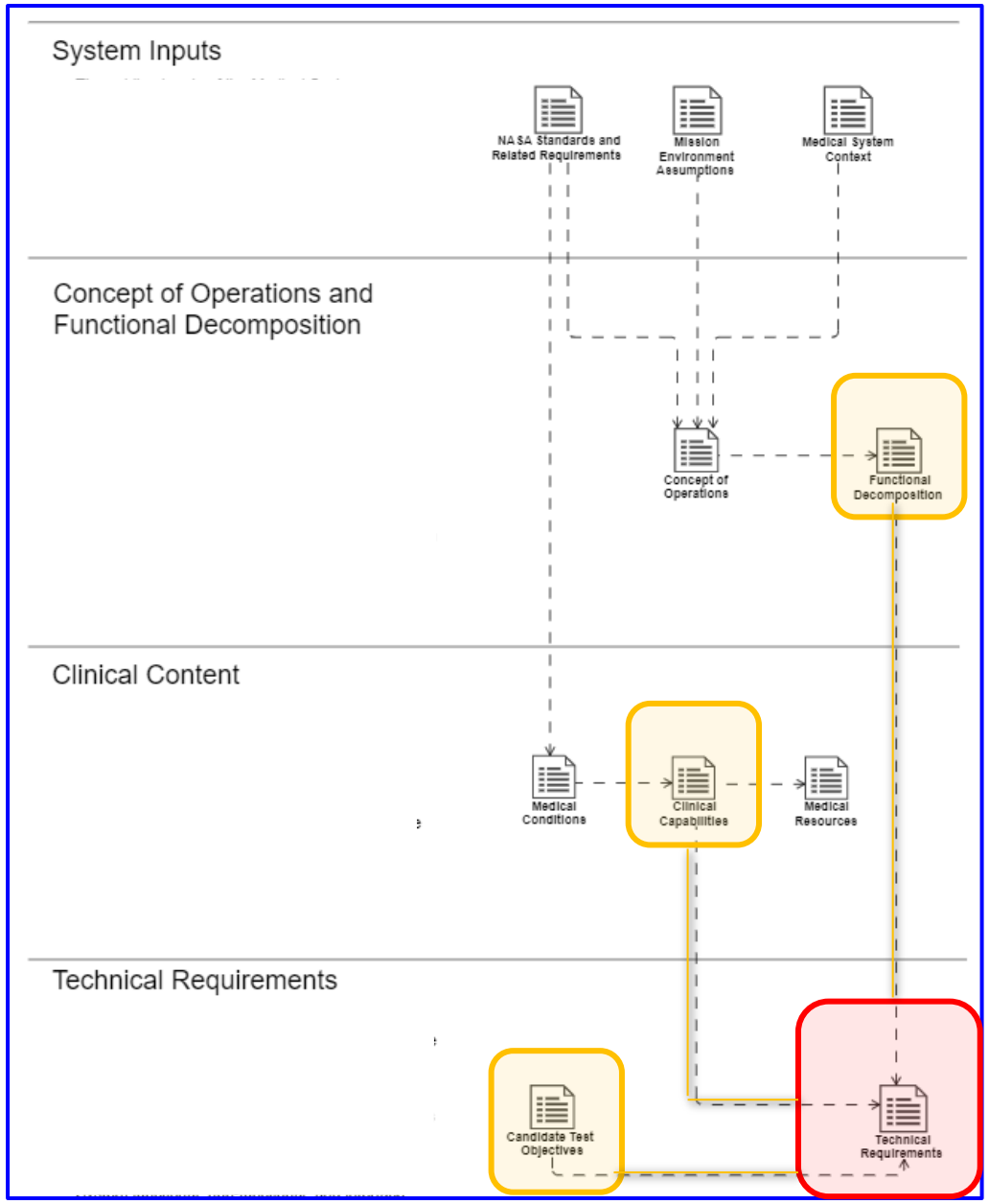
Medical System Capabilities

Derived from Medical Conditions

+

Candidate Test Objectives

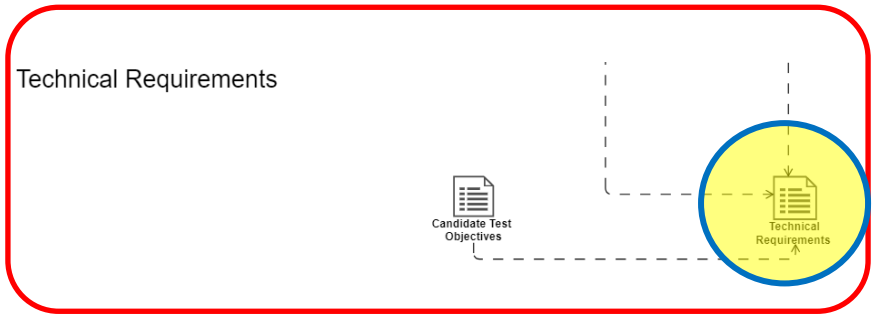
= **Medical System Requirements**



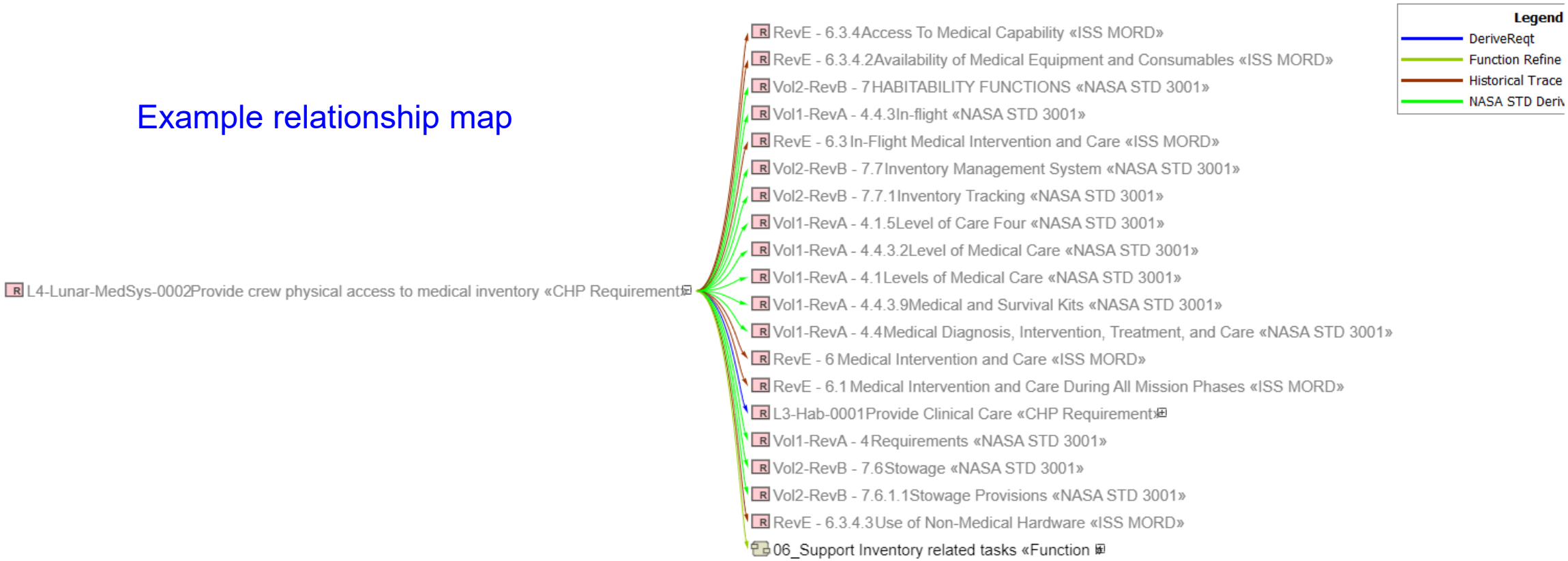
Technical Requirements

Links to:

- **Medical System Level 4 functional, non-functional, and interface requirements**
- **Medical system requirement relations**



Example relationship map



Representative Use Cases for standalone LDLOLS Foundation

1. Tailor LDLOLS foundation content to align with mid-phase, sustaining Artemis missions beyond Artemis V

2. Iterate on the LDLOLS ConOps to develop ConOps for extended Artemis/Mars Transit Habitat mission design and planning

3. Determine requirements not met if a specific capability or resource is removed (e.g., removal of ultrasound)

4. Provide requirements recommendations to assist the work of potential commercial partners

Summary

- **With the development of this LDLOLS Foundation, ExMC believes that we have:**
  - Established a systematic and repeatable medical system design process that combines clinical and systems engineering inputs to enable the integration of medical capabilities into exploration vehicle design and mission planning
  - Helped to build a bridge between the medical and engineering domains for improved communication and understanding
  - Created a system model that can repeatedly provide traceable, evidence-based system development products
  - Developed a process that can be extended to all Crew Health and Performance domains (not just medical)

BACKUP

What is the Medical System Foundation?

- The ExMC Medical System Foundation for Level of Care IV: Long-Duration Lunar Orbit and Lunar Surface Missions (LDLOLS) contains:
  - A Concept of Operations baselined to deep space, long-duration exploration missions
  - A corresponding medical condition set and identified clinical capabilities
  - Recommended medical system functional requirements and resources

- We followed the same robust process that ExMC created for the Short Duration Lunar Orbital Foundation presented in 2020.
  - The Short Duration Foundation is available on the ExMC site:

  Medical System Foundation for Level of Care IV: Short-Duration Lunar Orbit

- In FY23, this LDLOLS Foundation model will be updated to align with the current 3001 versions:
  - 3001 Vol 1 Rev B Change 1
  - 3001 Vol 2 Rev C

Why now? Transit Habitat Pre-Phase A work is happening now!

Requests for medical system requirements will be here sooner than we think…